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DISTANCE ESTIMATION TRAINING WITH NIGHT VISION GOGGLES: A PRELIMINARY STUDY

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Aircrews have reported significant problems in depth perception and distance estimation with night vision goggles (NVGs). The purposes of this experiment were to develop a methodology for quantifying distance estimation abilities with NVGs and to examine the value of a simple training procedure as a means of reducing errors. Absolute distance estimates were obtained from eight male aviators using Aviator's Night Vision Imaging System (ANVIS) AN/AVS-6 NVGs before and after exposure to a set of known distances. The results revealed that distance estimates were linear and significant reductions in errors and variability followed exposure to the training procedure. The results are discussed within the context of previous research. Issues for future research are addressed.

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PREFACE

This work was conducted by the Armstrong Laboratory, Aircrew Training Research Division (AL/HRA), with support from the University of Dayton Research Institute (UDRI). Both are located in Mesa, AZ. This work was conducted under Work Units 1123-32-06, Night Vision Device Training Research, and 1123-03-85, Flying Training Research Support. UDRI, working under contract F33615-90-C-0005, supports AL/HRA by supplying night vision device (NVD) subject matter expertise in the areas of NVD research, development, test and evaluation.

This report describes an experiment that evaluated a training procedure to aid night vision goggle (NVG) operators in making distance estimates. More specifically, the experiment examined the effect that NVGs have upon distance estimation as well as the effectiveness of a simple "perceptual calibration" technique in reducing estimation errors.

The authors would like to thank Capt Scott Middleton (AL/HRA) for his help in data collection and Mr. Brady Antonio (UDRI) for his help in designing the testing apparatus. Also, thanks to Mr. Deke Joralmon (UDRI), Dr. Chuck Antonio (UDRI), and Col William Berkley (AL/HRA) for overseeing NVG adjustment and visual acuity measurement procedures and to Ms. Marge Keslin (UDRI) for her superb editorial support. Finally, thanks to all the people who volunteered to serve as subjects in this experiment.

DISTANCE ESTIMATION TRAINING WITH NIGHT VISION GOGGLES: A PRELIMINARY STUDY

INTRODUCTION

Distance judgment and depth perception are fundamental skills required in aviation. Unfortunately, little is known about how these skills develop, how stable they are, what asymptomatic levels of performance are possible, or how much within- and between-person variability exists. This is particularly true for adults operating in large volumes of three-dimensional space. Distance estimation is not formally taught in pilot training and rules of thumb are typically passed on from instructor to student in an informal and invalidated manner. It is assumed that these skills will develop as a natural by-product of flying activities.

Modern military aircraft have avionic suites that provide information that can be used to aid in making judgments of distance. When data from these sources (e.g., radar altimeter, target tracking radar, laser range finder, inertial navigation) are combined with perceptual experiences of the corresponding visual array of the outside world, the pilot talks about "calibrating his eyeballs." That is, he repeatedly and somewhat systematically pairs visual percepts with valid distance data to form an internal perceptual calibration that he will rely on when circumstances do not permit cross-checking instruments. Anecdotal evidence from pilots' self reports and inferences from mishap investigations suggest that this internalized perceptual yardstick tends to break down when there are substantial changes in the visual environment, particularly when the visual array is impoverished or ambiguous.

Inaccurate distance estimation with night vision goggles (NVGs) has been identified as a serious problem by aircrew members (Crowley, 1991; Donohue-Perry, Hettinger, & Riegler, 1992) and has been implicated as a factor in some rotorwing accidents (Fuson, 1990). This problem is of particular concern to helicopter crew members who often need to estimate distances from their position to an object as well as between two objects during hover and landing phases of flight. For example, they must judge whether the helicopter rotor blade will clear an obstacle or whether a landing zone (LZ) is wide enough to land safely. The crucial distances are within 150 ft, with the most important distances ranging from 40-60 ft (typical range of rotor blade lengths).

Previous Research

Distance estimation research with NVGs at distances greater than 20 ft has been very limited. Foyle and Kaiser (1991) examined the issue at distances between 20 and 200 ft with AN/AVS-6 NVGs. The results of their study revealed that half of the subjects (helicopter pilots with NVG experience) underestimated distances and half of the subjects overestimated distances.

The only other study addressing far distance estimation with NVGs was conducted by Wiley, Glick, Bucha, and Park (1976). They examined distance judgments with generation II NVGs (AN/PVS-5) at distances between 200 and 2,000 ft. Their results revealed that NVG distance judgments were significantly worse than unaided daylight monocular and binocular distance judgments.

Although distance estimation problems with NVGs have been acknowledged and documented, attempts to remedy the situation have been lacking. There have been attempts to improve unaided distance estimation through training. Gibson and Bergman (1954) demonstrated that corrective feedback can improve absolute distance estimation. They reported a reduction in error of 19% after training and concluded that subjects were able to associate changes in perspective and texture gradient distance cues with changes in distance.

In a follow-on study, Gibson, Bergman, and Purdy (1955) examined distance estimation training to determine whether improvements brought about through training will transfer to a new location. An experimental group was trained via a method of fractionization and was given a scale of measurement to aid in making judgments. A control group was given no scale. The experimental and control groups were then tested on absolute distance estimation in a different area than that of the training. The results revealed that the training group performed better in both absolute error and estimation variability than the control group.

The Present Study

The results of the Gibson et al. (1954; 1955) studies prompted the use of a similar methodology in the present study. However, in the present experiment, distance estimates were made between object-to-object (exocentric) distances and between person-to-object (egocentric) distances while wearing NVGs. The training technique used a perceptual calibration procedure that involved having the subjects examine the targets at known distances. This procedure was chosen, in part, because it could easily be implemented at most operational locations at a low cost.

METHOD

Apparatus

Test Area. The testing was conducted in a large field containing dirt, grass, and very small shrubs. The only immediate distance cues available to the subjects were gradients of texture density, binocular disparity, and motion parallax. A few trees were visible about 300 yds away from the test area. Some cultural lights were visible in the distance. None were located within 3 mi of the direction of gaze of the test area, most were more than 15 mi away. Dispersed about the area were 13 targets consisting of numbered white isosceles triangles, 40 in. high and 27 in. across the base. The targets had a reflectance of 70.12% and the numbers on the targets had a reflectance of 17.30%. The test area, depicted in Figure 1, was set up so that one target would be positioned within each 10 ft range from 20 to 140 ft from the subject. Thus, there were 12 subject-to-target (egocentric) distances. Target positioning also was constrained so that each egocentric distance would have an equivalent [+/- 3 ft] target-to-target (exocentric) distance; an extra target was used to fulfill this positioning constraint. Therefore, the total number of distances being judged was 24. Table 1 presents the target numbers that comprised the 12 egocentric and 12 exocentric distances. Figure 1 depicts the test area (subjects viewed the area from position "s").

Table 1. Target Numbers Comprising the Egocentric and Exocentric Distances During Testing

Egocentric		Exocentric	
Targets	Distance (ft)	Targets	Distance (ft)
(S,1)	135	(3,10)	135
(S,4)	125	(3,11)	123
(S,7)	112	(2,1)	114
(S,8)	105	(2,11)	105
(S,2)	95	(4,11)	95
(S,11)	85	(13,1)	82
(S,9)	77	(1,9)	75
(S,5)	65	(11,7)	67
(S,13)	56	(9,6)	53
(S,10)	46	(13,11)	45
(S,12)	34	(11,5)	32
(S,6)	28	(13,9)	25

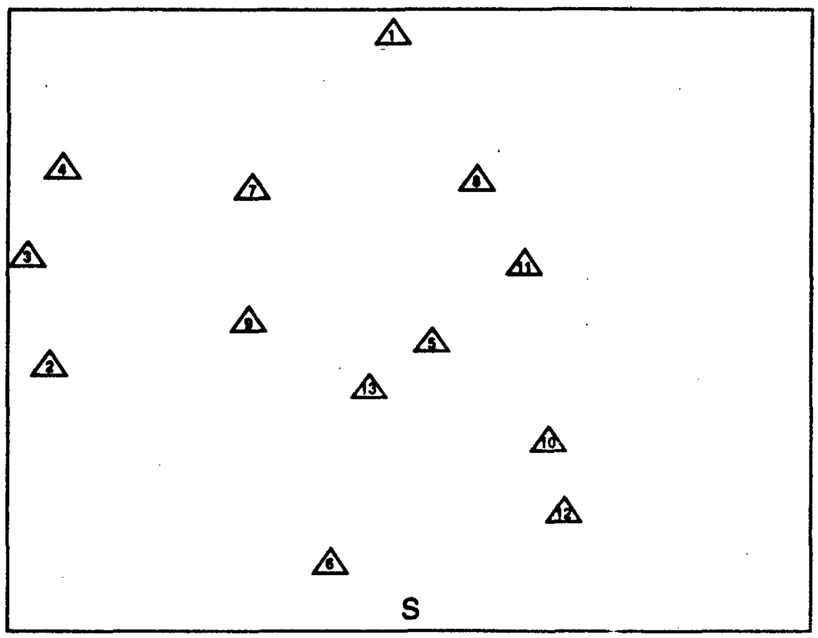

Figure 1
Representation of the Test Area

Training Area. The training area, depicted in Figure 2, was stationed away from but in the same field as the test area. Eleven targets similar to the ones used in the test area were placed at known distances from the subject. Next to targets 1 through 7 were signs indicating the exact distance between a subject and that target when standing directly in front of it. The signs marked off 20 ft increments from 20 to 140 ft and were positioned 20 ft apart, diagonally across the field of view (FOV). The subject viewed the targets from an observation area perpendicular to each sign (positions "A-G"). Four targets were dispersed near the area of the seven other targets to create exocentric distances (targets 8 through 11). The training distances consisted of a total of 42 (21 egocentric and 21 exocentric) and are presented in Table 2 according to viewing location. While there was an equivalent number of egocentric and exocentric distances, some exocentric distances were not presented, whereas other exocentric distances were presented more than once. This was an experimental error that was discovered after testing.

Subjects

Eight male military pilots from the U.S. Air Force volunteered for the study. Age ranged from 30 to 47 years with a mean of 39.7 years. Flight experience ranged from 1,200 to 5,500 hrs, with a mean of 2,796 hrs. Only one subject had NVG experience, which was 200 hrs with generation II NVGs. The subjects all had 20/20 vision or better (including corrections) and could achieve at least 20/40 visual acuity with NVGs as tested in an NVG eyelane with a standard NVG resolution chart.

Experimental Design

The study employed a 2 x 2 within-subjects factorial design. The independent variables consisted of TEST TIME (pre-training, post-training) and DISTANCE TYPE (egocentric, exocentric). The

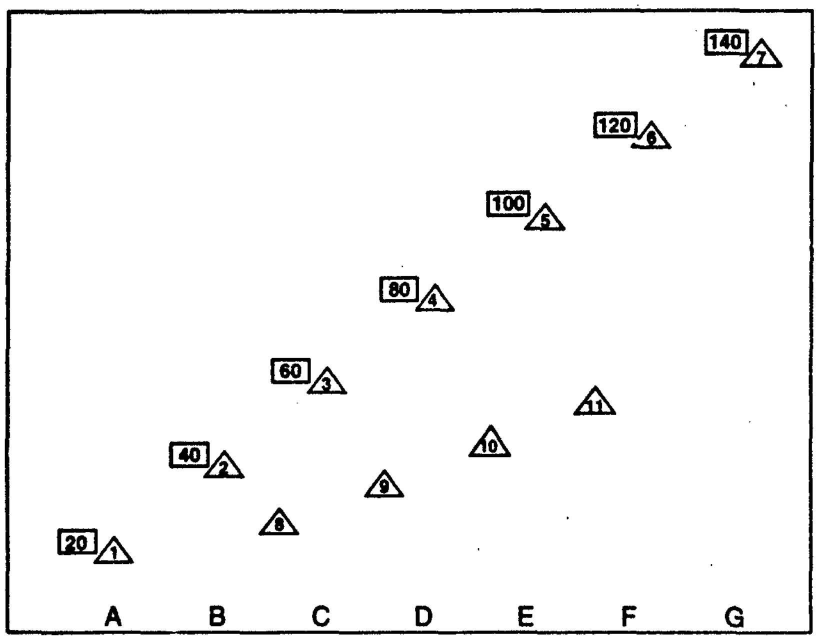

Figure 2
Representation of the Training Area

Table 2. Target Numbers Comprising the Egocentric and Exocentric Distances During Training According to Viewing Location

Viewing Location	Egocentric Targets	Egocentric Distance (ft)	Exocentric Targets	Exocentric Distance (ft)
A	(S,1)	20	(1,8)	32
A	(S,8)	46	(1,9)	74
A	(S,3)	62	(3,9)	53
B	(S,2)	40	(2,8)	19
B	(S,9)	76	(2,9)	61
B	(S,4)	79	(8,4)	44
C	(S,3)	60	(1,8)	32
C	(S,10)	94	(1,9)	75
C	(S,1)	35	(3,8)	26
D	(S,4)	80	(4,11)	84
D	(S,11)	110	(4,9)	53
D	(S,8)	38	(9,11)	58
E	(S,5)	100	(5,9)	61
E	(S,9)	48	(9,10)	31
E	(S,2)	62	(5,8)	62
F	(S,6)	120	(6,11)	72
F	(S,3)	84	(3,11)	97
F	(S,11)	93	(10,11)	27
G	(S,7)	140	(3,10)	75
G	(S,8)	77	(1,10)	105
G	(S,3)	97	(3,8)	26

dependent variables consisted of both absolute and relative absolute judgment errors and standard deviation of the absolute judgment errors.

Procedure

Subjects were first taken to the NVG eye lane where NVGs and helmets were fitted and adjusted, and NVG visual acuity was measured. Subjects were then transported to the test area. Subjects gave distance estimates twice for each of the 24 intervals. The order of distance presentation was randomized for all sequences. After pre-training, subjects were taken to the training area where they were told of the nature of the training setup, including the spacing of the targets among the field.

Subjects were then positioned in front of each sign and were told specific egocentric and exocentric distances. For example, at position A (see Fig. 2) subjects were told that the distance between them and target 1 was 20 ft, between them and target 8 was 46 ft, between them and target 3 was 62 ft, between targets 1 and 8 was 32 ft, between targets 1 and 9 was 74 ft, and between targets 3 and 9 was 53 ft. The subjects then moved to position B and were given six more distances to examine. Subjects were told to study the distance intervals in order to "calibrate their eyes" to the NVG display. The training lasted for approximately 10 min. Subjects were then taken back to the test area for a post-training evaluation. The same distances used in the pre-training evaluation were judged by the subjects. Testing and training were conducted under starlight conditions. The night vision imaging system radiance (NR) from a target measured during one of the testing nights was 4.5×10^{-10} NR.

RESULTS

The results were analyzed in terms of regression, error, and subject variability. As mentioned previously, the egocentric and exocentric distance types were not exactly equal (some differed by as much as 3 ft). The measures computed during statistical analysis were based upon the exact distance for the two distance types. However, for presentation purposes the ego- and exocentric distances were treated as equal.

Regression Analysis

In order to provide an indication of the relationship between actual distance and estimated distance, a regression analysis was conducted. The regression equations were developed based upon the results of an Analysis of Covariance (ANCOVA) with ACTUAL DISTANCE as the covariate. The ANCOVA revealed that the ACTUAL DISTANCE X DISTANCE TYPE interaction was significant [$F(1,40) = 12.29$, $p =$

.001] with exocentric slopes significantly greater than egocentric slopes. No effects with the TEST TIME variable were significant in the ANCOVA results and thus, the regression equations are collapsed across TEST TIME. The regression equations, plotted in Figure 3, present mean estimated distance as a function of actual distance for both the egocentric and exocentric conditions. As can be seen, the individual data points fall in a linear pattern, with perceived distance increasing as does actual distance. The regression equations developed for the egocentric and exocentric conditions respectively are the following:

Estimated Distance = -2.063 + 0.861 (Actual Distance) and
Estimated Distance = -9.200 + 1.092 (Actual Distance).

The goodness of fit of these equations is confirmed by the large coefficients of determination, r^2, for each condition; egocentric = 0.984 and exocentric = 0.958. In addition, further examination of Figure 3 reveals that subjects tended to underestimate distance for all egocentric intervals. This trend accurately represents the individual data as well. Based upon a 75% criterion to classify distance estimation bias, five of eight subjects were classified as egocentric underestimators, with the remaining three showing no clear direction. Only three of eight subjects could be classified as underestimators for exocentric distances, with two classified as overestimators and three showing no direction. It should be noted that the egocentric slope (SE = 0.035) is significantly less than 1 [$t(10) = -3.37$, $p < 0.01$], whereas the exocentric slope (SE = 0.073) is not significantly greater than 1.

Mean Absolute Error

The primary interest in this study was to determine if estimation error decreased after training. In addition, it was of interest to examine differences between egocentric and exocentric

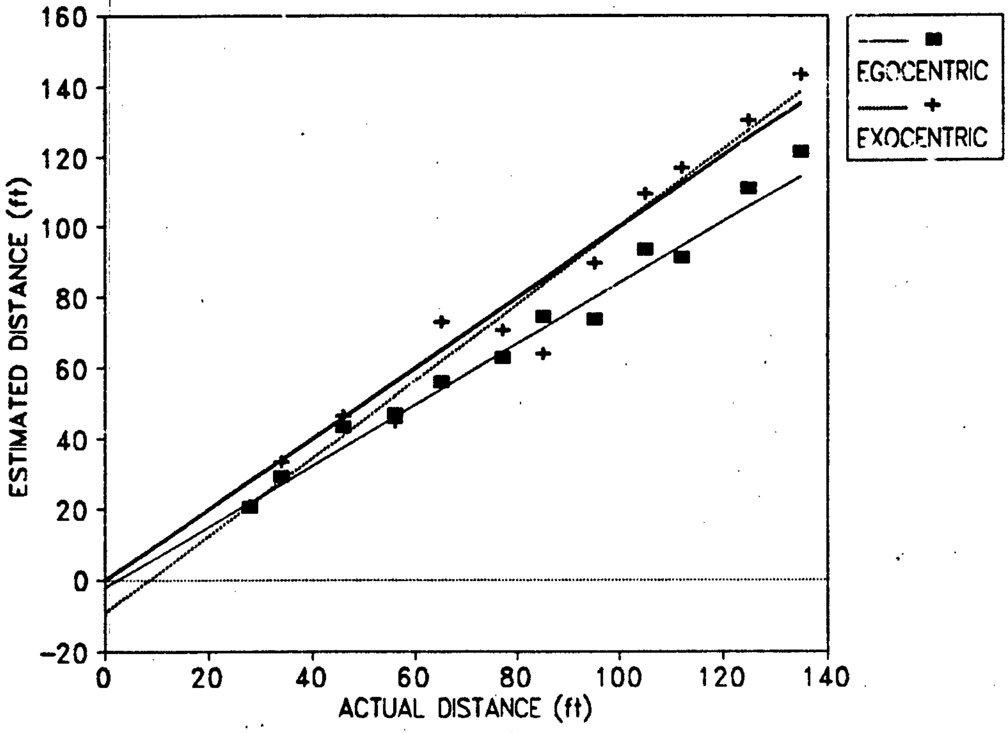

Figure 3
Regression Plots for the DISTANCE TYPE Condition as a Function of Estimated and Actual Distance

distance judgments to see if training differentially affected one type of distance judgment. A 2 x 2 within-subjects Analysis of Variance (ANOVA) was conducted on the absolute error data. Table 3 presents the results of the ANOVA, revealing a main effect of TEST TIME [$F(1,21) = 30.04, p < 0.001$]. Neither the main effect of DISTANCE TYPE nor the interaction of TEST TIME x DISTANCE TYPE were significant.

Table 3. Mean Absolute Error ANOVA Summary Table

Source	Degrees of freedom	Sum of squares	F Value	p
Test time	1	1451.26	30.04	<0.001
Distance type	1	3.50	0.07	0.790
Time x Type	1	4.75	0.10	0.757
Error	21	1014.44		

Figure 4 presents a plot of the means for the TEST TIME variable. As can be seen, mean absolute error decreases after training. The effect of training can be examined further in Figure 5. This graph plots the mean absolute error (collapsing across distance type) as a function of each distance and shows that most of the error occurs at the longer distances. There is also a decrease in error after training for all the distances.

Relative Absolute Error

Relative absolute error was computed to equalize the magnitude of error across the various distances. As was the case with absolute error, a 2 x 2 within subjects ANOVA was conducted on the data. The results parallel the absolute error data with only a significant main effect of TEST TIME [$F(1,21) = 28.79, p < 0.001$]. These results are depicted in Figure 6 and show a decrease in relative absolute error after training from 31% to 15%.

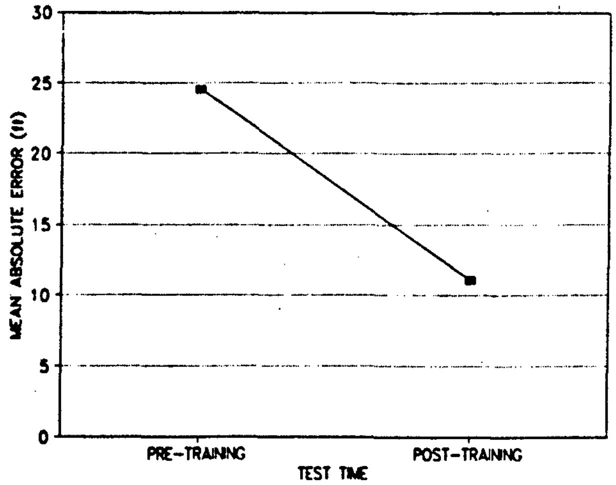

Figure 4
Mean Absolute Error as a Function of TEST TIME

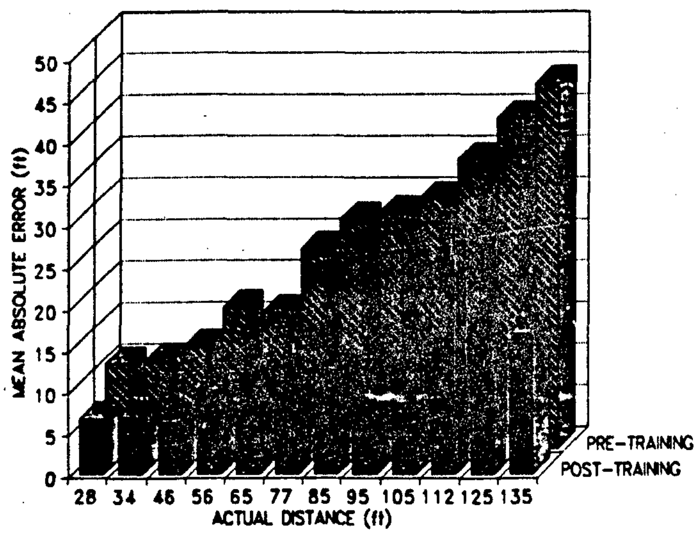

Figure 5
Mean Absolute Error as a Function of
Actual Distance and TEST TIME

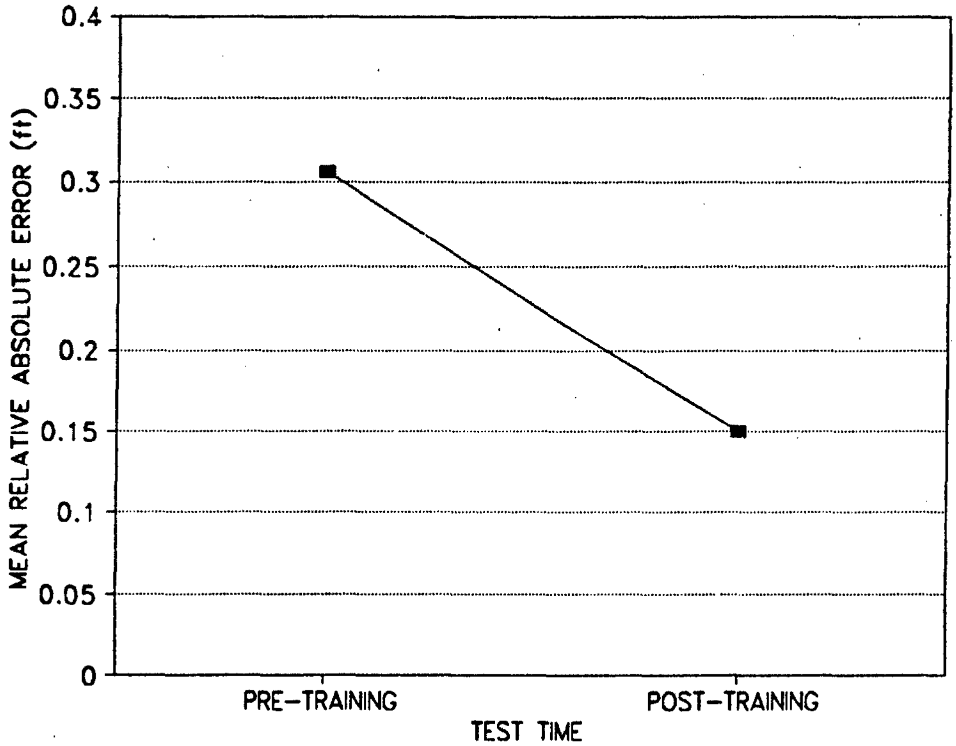

Figure 6
Mean Relative Absolute Error as a Function of TEST TIME

Standard Deviation of the Absolute Error

Another measure of the effect of training is subject variability. The standard deviation of the absolute error was analyzed by a 2 x 2 ANOVA. The results are displayed in Table 4. The analysis revealed that only the main effect of TEST TIME was significant [$F(1,21) = 23.37$, $p < 0.001$]. The mean standard deviations for the group are displayed in Figure 7. As can be seen, subject variability decreases after training. Figure 8 displays the effect of training upon subject variability in terms of each distance and reveals that variability decreases after training at all distances. There is a trend for variability to be higher at longer distances than shorter ones during both pre- and post-training.

Table 4. Standard Deviation of the Absolute Error ANOVA Summary Table

Source	Degrees of freedom	Sum of squares	F Value	p
Test Time	1	412.73	23.37	<0.001
Distance Type	1	25.46	1.44	0.243
Time x Type	1	1.53	0.09	0.771
Error	21	370.92		

DISCUSSION

The results of the regression analysis revealed two important aspects of NVG distance estimation: linearity of the data and direction of estimation bias. Distance judgments appear to be nearly linear as indicated by large coefficients of determination. This finding is consistent with previous research with unaided vision in natural outdoor settings (e.g., Gilinsky, 1951; Gibson & Bergman, 1954; Gibson, et al. 1955; Teghtsoonian & Teghtsoonian, 1970). However, in most of these cases a typical psychophysical

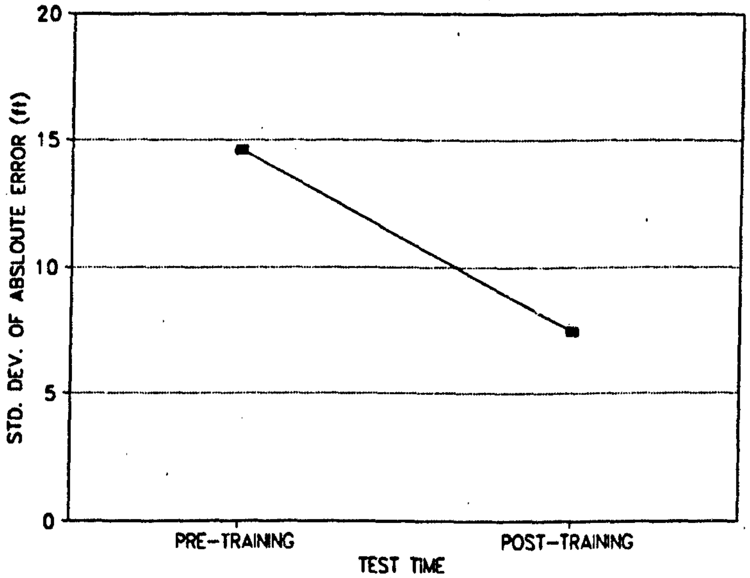

Figure 7
Standard Deviation of Absolute Error as a Function of TEST TIME

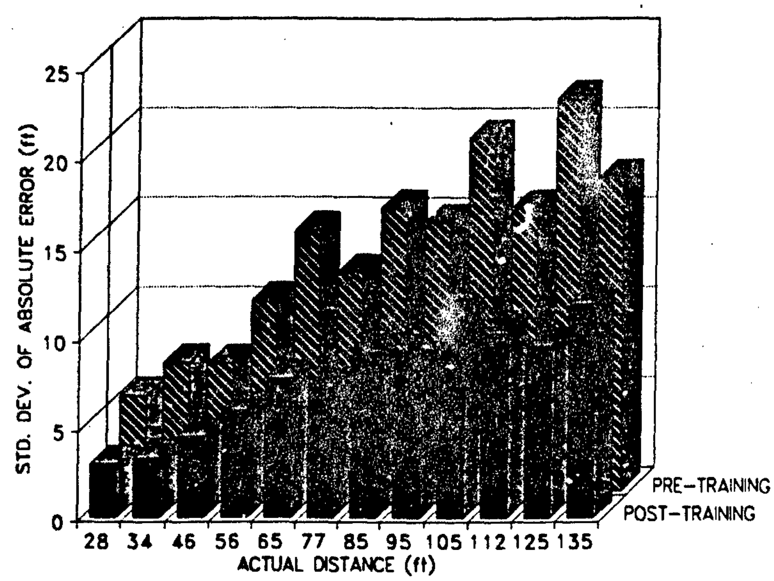

Figure 8
Standard Deviation of Absolute Error as a Function of Actual Distance and TEST TIME

power function relationship was found, requiring a log transform of either the estimate and/or the actual distance. Data from this study did not require a log transform in order to achieve a linear relationship. The significance of this difference at this point is not known and could be due to a number of methodological factors. However, it could reflect a more fundamental difference due to the characteristics of the NVGs.

The second point to be mentioned about the regression analysis is the apparent tendency to underestimate the egocentric distances and to be more accurate with exocentric distances. This finding is interesting to the extent that it reflects the performance of the individual subjects. In fact, five of the eight subjects could be classified as egocentric underestimators. However, three subjects did not have a consistent bias. Recall that Foyle and Kaiser (1991) found that two subjects overestimated and two underestimated distance. It seems that some individuals will exhibit a clear bias but it is by no means always in the same direction. From a purely practical standpoint, the tendency to underestimate is not as dangerous as the reverse.

The fact that more accurate estimates are associated with exocentric distances is surprising since all subjects reported that the exocentric judgments were more difficult. In addition, a few of the exocentric judgments required extensive scanning due to the wide angular separations of the targets. Levin and Haber (1993) have recently demonstrated that when the actual distances are held constant, the angular separation becomes a significant factor in judging distances, leading to overestimation as the angle increases. Since the experimental setup for this study did not attempt to control for this factor, no conclusions can be drawn regarding the role of angular separation between the targets. However, according to Levin and Haber, all exocentric distances will be overestimated when compared to equivalent egocentric distances. This may partially explain why exocentric judgments were not underestimated like their counterpart egocentric distances. Furthermore, it may be that the increased scanning associated with exocentric distances enhances the motion parallax distance cue in a manner that overcomes an underestimation bias associated with NVGs in this study. Elucidation of this pattern will require additional research.

Our primary interest was to determine if training decreased estimation errors regardless of whether they originally overestimated or underestimated the distance. Results of the analysis showed that there was a significant decrease in absolute error after training (46.1%). However, as Figure 5 reveals, error is still as high as 8 ft at the crucial distances (40-60 ft). The analysis also revealed that training was equally effective for both egocentric and exocentric distances. This effect was not expected since the training procedure design did not allow for the exact replication of the exocentric angular separations that were used during testing, and there was a disproportionate number of exocentric distances presented in the training period. Despite these limitations, it appears that exposure to exocentric distances is effective in reducing absolute error.

A major focus of this study was the development of an operationally practical procedure that can be used to study and train distance estimation when using NVGs. In that context, the emphasis is on absolute error. However, it is also of value to discuss the use of relative error as a dependent measure. The results of the relative absolute error analysis revealed a decrease from 31% to 15% after training. Foyle and Kaiser (1991) obtained a relative absolute error of roughly 20% with AN/AVS-6 NVGs. The fact that the error obtained in their study is 11% lower may be due to the experience of their subjects. All of their subjects were helicopter pilots with NVG experience. The subjects we used had no NVG experience and were mainly fixed-wing pilots.

Almost as important as the reduction in error is the reduction in variability between subjects' estimates that occurs after training. One desirable outcome of any training program would be to develop uniformity as well as accuracy in judgments. For example, if distance estimates are more uniform among subjects, error is less likely to occur when communicating location information. Communication of distance is a primary task in rotorwing operations because a pilot often relies upon verbal feedback from both the side and tail scanner crew members for position information. Subject variability in the amount of distance estimation absolute error was shown to significantly decrease after training. Thus, subjects' perception of distance became more uniform. However, subjects still vary as much as 8 ft on the crucial distances (40-60 ft) after training.

CONCLUSION

Because there was no control condition in the present study, it would be premature to conclude that the training procedure was responsible for the reduction in errors and variability. However, these data are consistent with previous research using similar procedures with unaided vision. Assuming for the moment that the training procedure was an effective technique, there are a number of issues about the training that remain to be addressed. Are there more effective techniques that can be employed within the constraints of the operational environment? How accurate can people get with additional training? How accurate do they need to be? How long will this skill last? Will static ground-level skill transfer to dynamic in-flight situations? Will skill transfer to other illumination (e.g., moon phase) conditions? Is there a systematic relationship between one's ability to judge distance during day-unaided conditions and judgments obtained using NVGs? Can people estimate distances better with more advanced NVGs such as the ANVIS F-4949? These and other issues will be addressed in future research.

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